Dust in the Atmosphere of Mars 2017
and Its Impact on the Human Exploration of Mars
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The Temporal and Spatial Distribution of Dust in the Atmosphere of Mars

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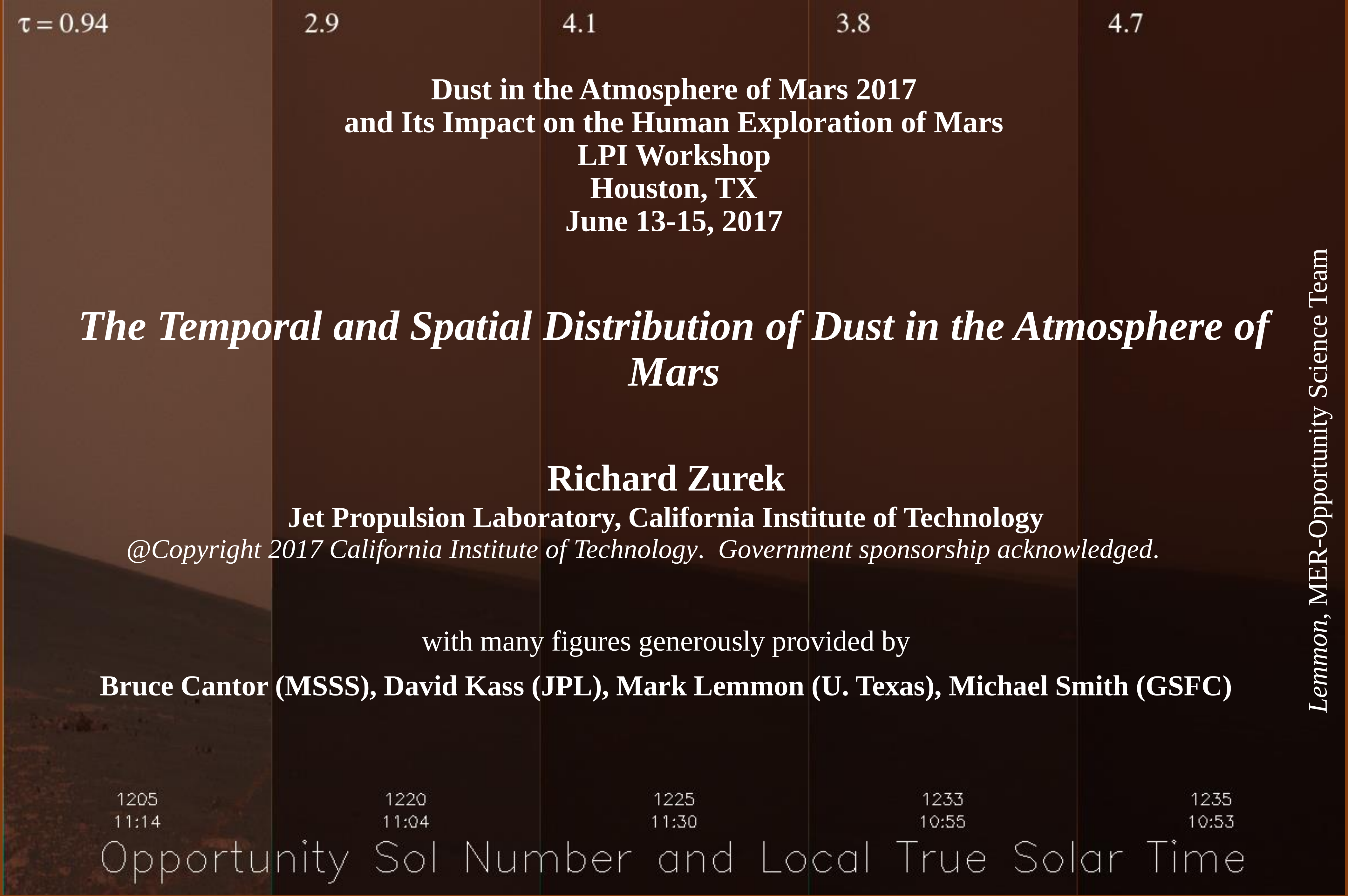
with many figures generously provided by

Bruce Cantor (MSSS), David Kass (JPL), Mark Lemmon (U. Texas), Michael Smith (GSFC)

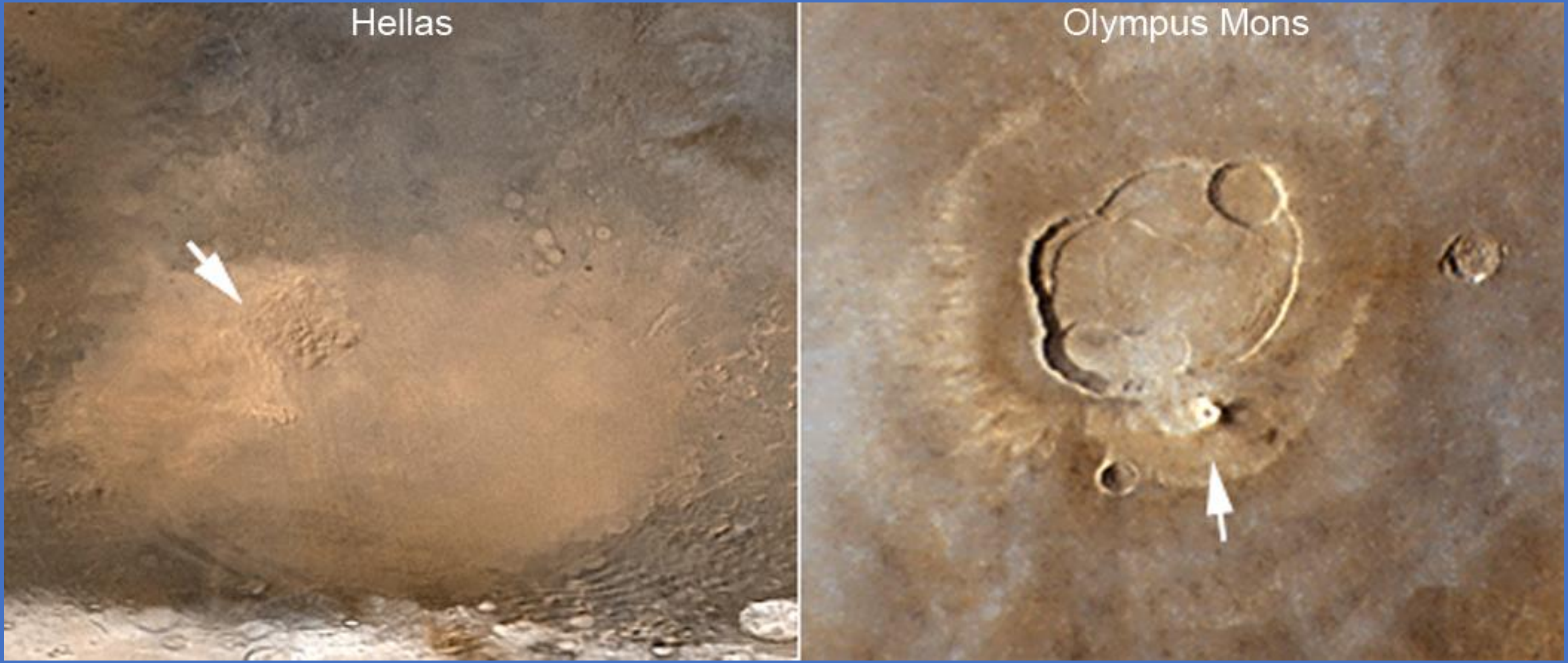


Lemmon, MER-Opportunity Science Team

Preview

- **There is *some* dust in the Mars atmosphere *everywhere* on the planet essentially *all the time* (the background dust haze)**
  - There may be clear atmospheric air in some air masses where dust has been scavenged but typically not for long outside the polar regions
  - There are some places on the surface where dust (the fine-grained particles < 50 μm in diameter) has been removed by the winds
  - The dust fall-out measured by Mars Pathfinder suggested that the solar-powered Mars Exploration Rovers could operate only for 90 sols—fortunately, the wind which can bring the dust can also remove it as well
- **The amount of atmospheric dust varies dramatically with season. Local dust storms and dust devils occur in all seasons and have been observed almost everywhere on the planet at some time. However, there are:**
  - Preferred zones and seasons for occurrence
  - Storm tracks which local dust storms repeatedly traverse
  - The very largest dust storms, covering areas the size of Earth continents and even global domains, tend to occur during southern spring and summer, when Mars is closest to the Sun and the feedback of heating of the airborne dust is strongest.
    - Heating => temperatures => pressure => winds => dust-raising => more heating
    - However, large storms can occur in other seasons as well

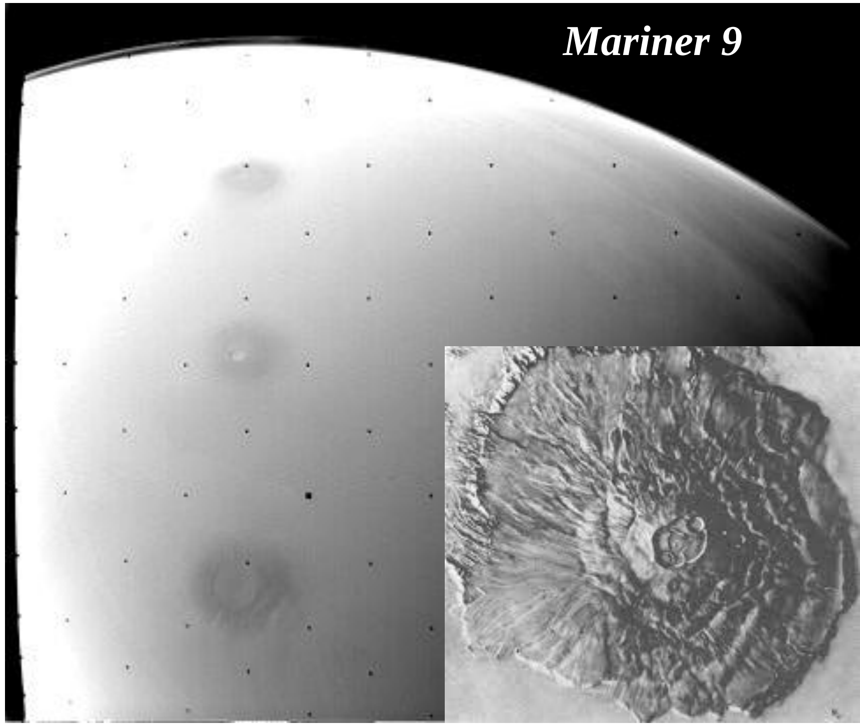
High or low altitude – dust storms can occur



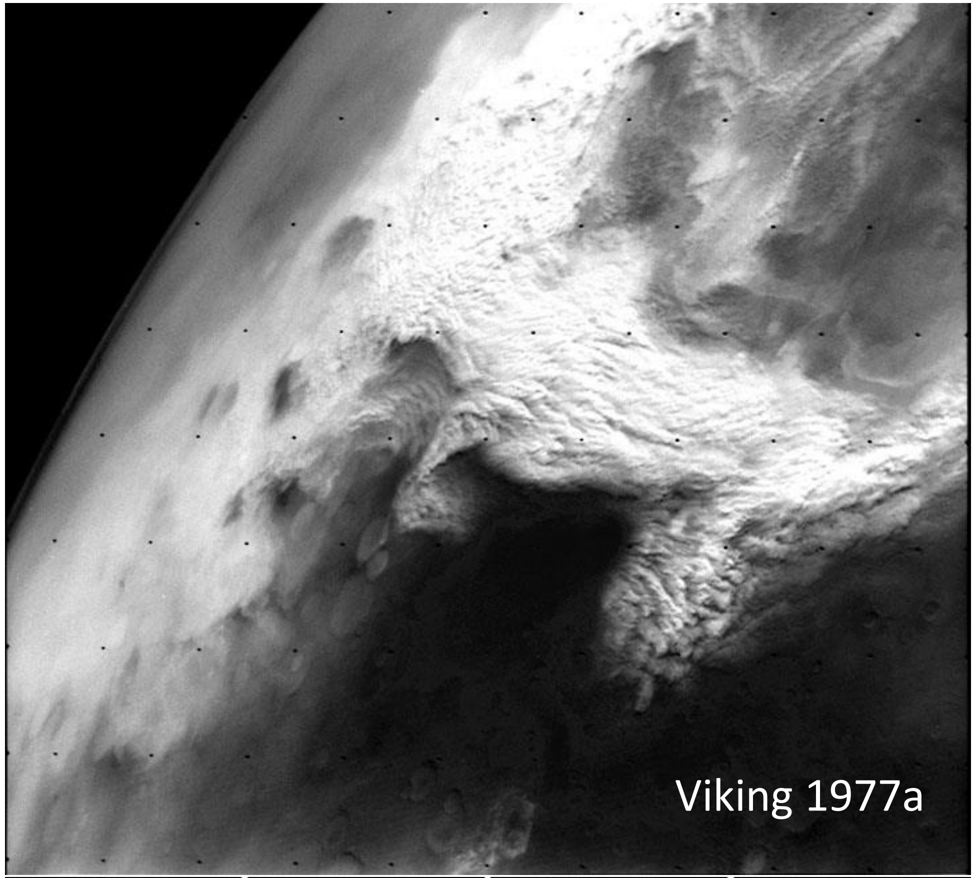
Courtesy of B. Cantor MSSS / JPL / NASA

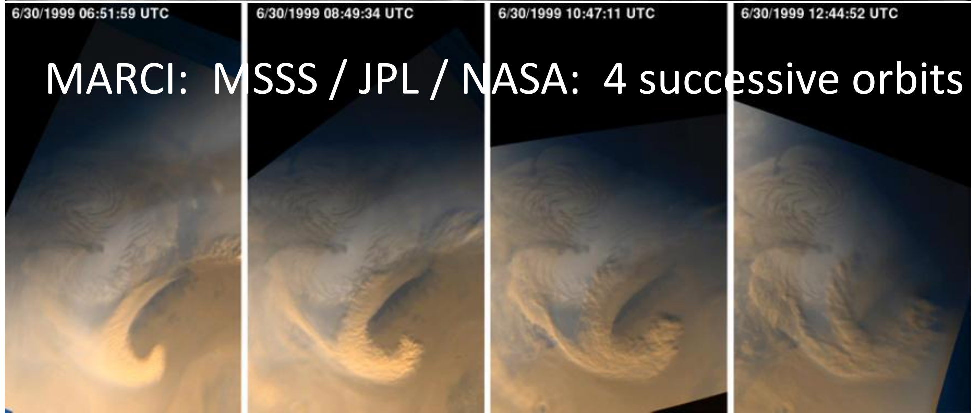
A Brief History

- The pervasiveness of atmospheric dust was not appreciated until 1965 when the Mariner IV radio occultation experiment indicated that the atmospheric surface pressure on Mars was >10 times less than the expected ~85 hPa.
    - Scattering by the airborne dust increased the effective path of sunlight reflected from the surface leading to an overestimate of atmospheric gas absorption and thus gas abundance.
- Dust storms were known, but were essentially "yellow clouds that moved". In the telescopic observations, limited largely to oppositions of Earth and Mars, storms were rare enough that they were noted when observed.
    - The largest storm confidently recorded in the historical data base occurred in 1956.
        - We now routinely use that date (MY1) to mark Mars years since that great event
- The real clincher regarding dust storms was the arrival of Mariner 9 in orbit during a global dust storm event that obscured most of the planet.
    - This remains the most global dust event observed, reaching heights of 70km or more and lasting for several months.



Some Things to Remember (1 of 2)



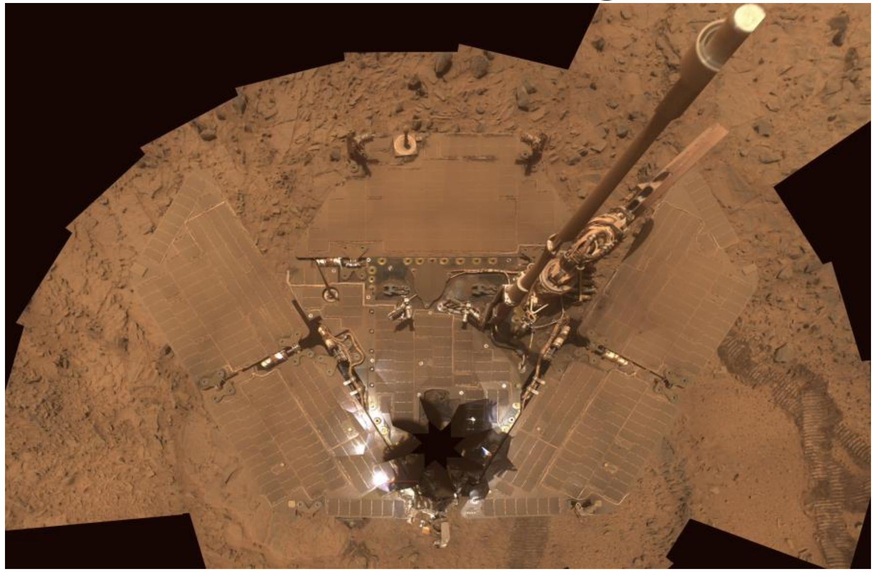


- Storm description has evolved in the spacecraft era because of better spatial resolution and, in the last 2 decades (1 Mars decade), almost continuous daily coverage, albeit only at early afternoon local times
  - Active dust raising regions can be detected from their opacity and morphology
  - Extent and opacity of dust hazes can be more confidently mapped
  - Opacities can be estimated from orbit and from the ground, with different coverages of course
  - Measurements in the visible and IR can constrain particle size and composition
- Nomenclature
  - Here storm is used to designate an active dust-raising zone with associated dust haze (at some point merging into the "background")
  - Local dust storms: 1-3 sols, < 1.6 million km^2, can travel long distances; most dust is constrained to the boundary layer (~5 km)
  - Regional dust storms/events: > 1.6 million km^2 (~ 2.3 x Texas); few sols to a few weeks; dust gets higher (10-40 km)
  - Planet-encircling dust events: can cover parts of one hemisphere or be nearly global; many weeks to months; gets $\geq$ 70 km.

Some Things to Remember (2 of 2)

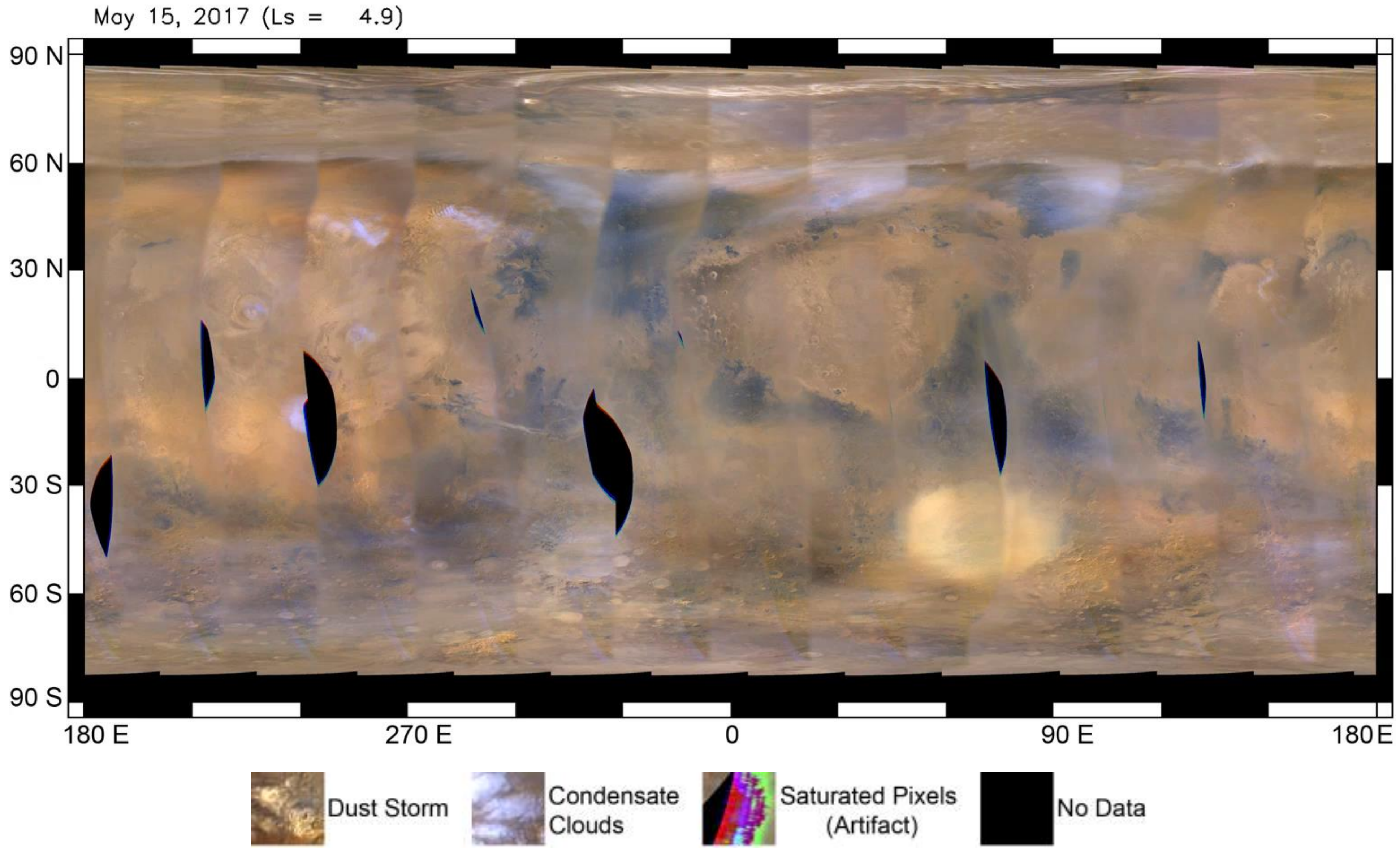
- Dust can be moved wherever it is present and winds are strong enough
  - Local dust storms frequently form in the polar jet streams at the seasonal polar cap edge.
  - Dust can be lofted into the atmosphere by saltation when surface winds ≥ 30 m/second or injected by vortex motion
- Dust falls out of the atmosphere by gravitational sedimentation (large particles fall fastest), including by scavenging when the dust become condensation nuclei for water/carbon dioxide ice aerosols
- Dust is not uniformly mixed. Dust layers can be lofted higher into the atmosphere
  - Typically, the longer the storm is active, the higher the dust can go or the longer it will remain at elevation.
- Dust is of interest to dynamicists because it is the movable, radiatively active agent in the Mars atmosphere. (Ice areosols are the other.)

Cantor: MARCI / MSSS / JPL / NASA

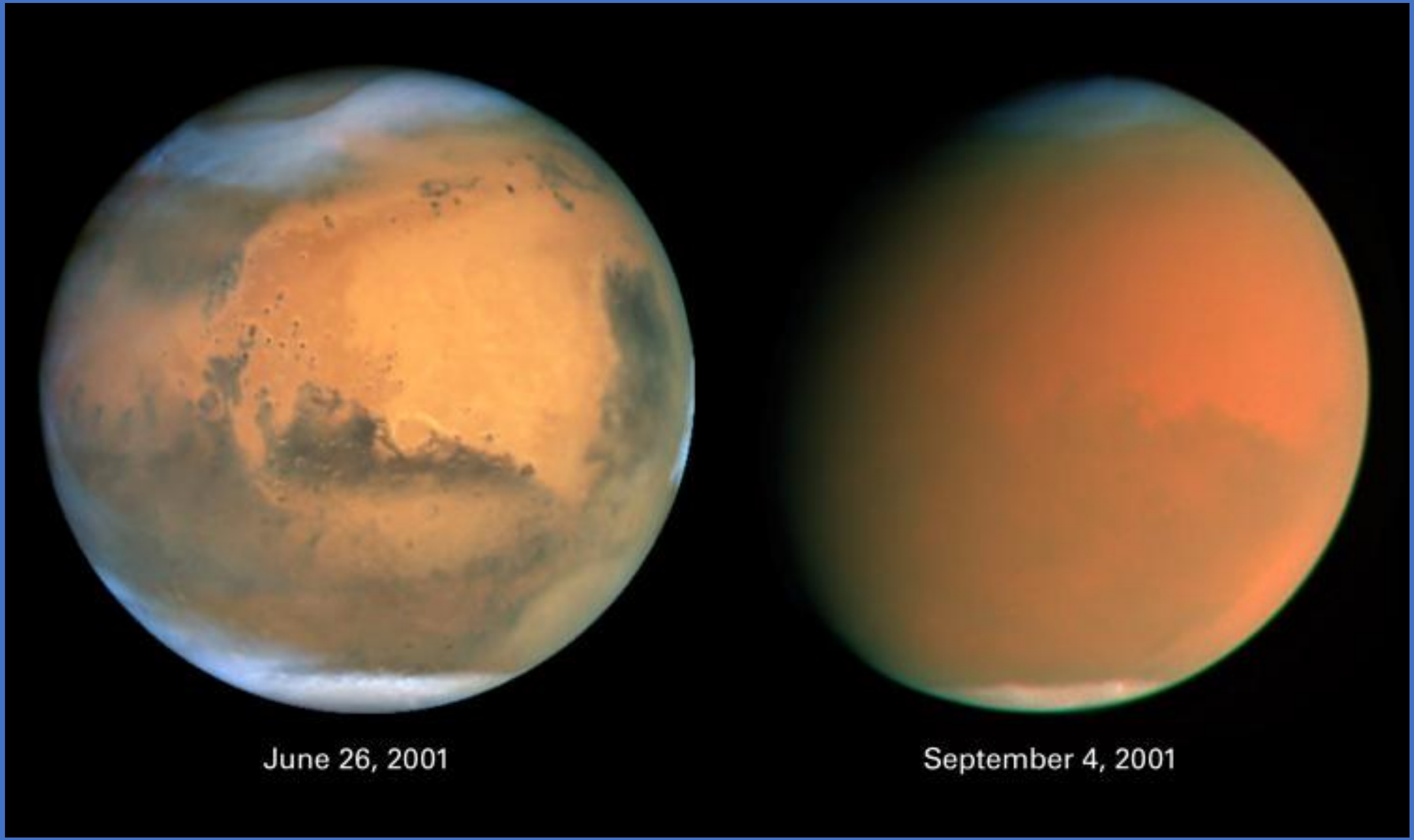


A dusty *Spirit* rover

Weather Conditions for Past Week



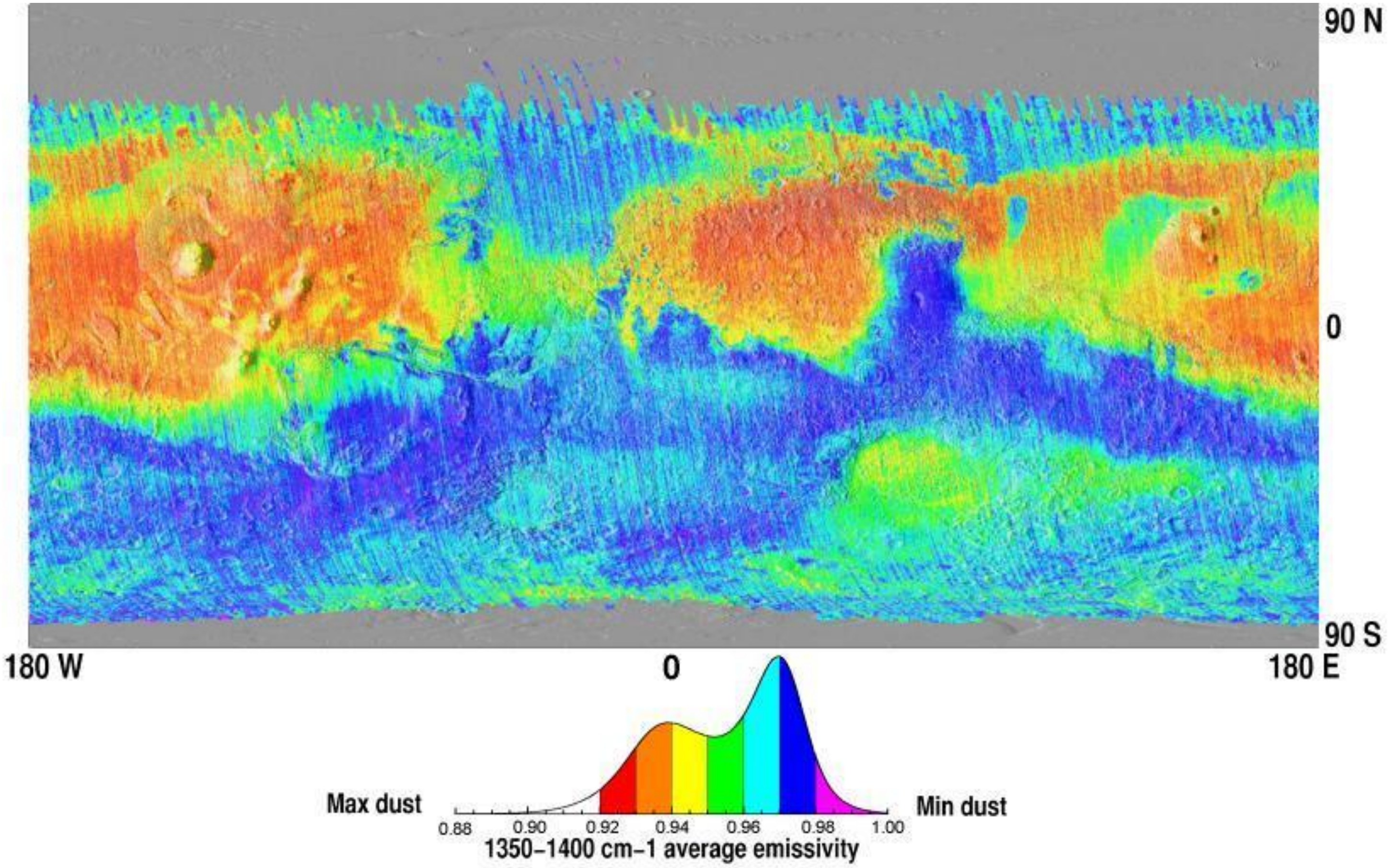
HST View in 2001

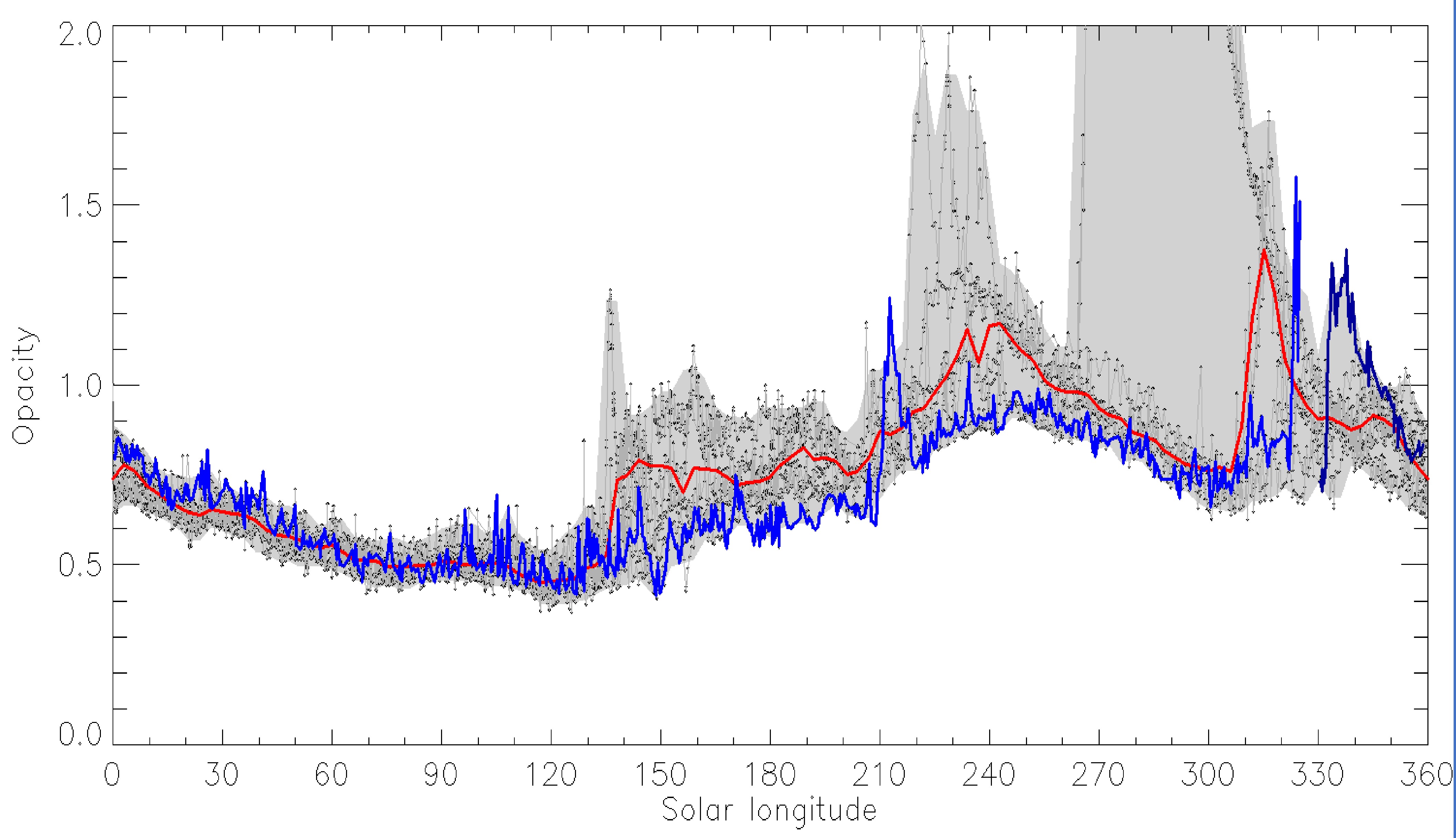


CREDIT: NASA / STScI / AURA / J. Bell & M. Wolff

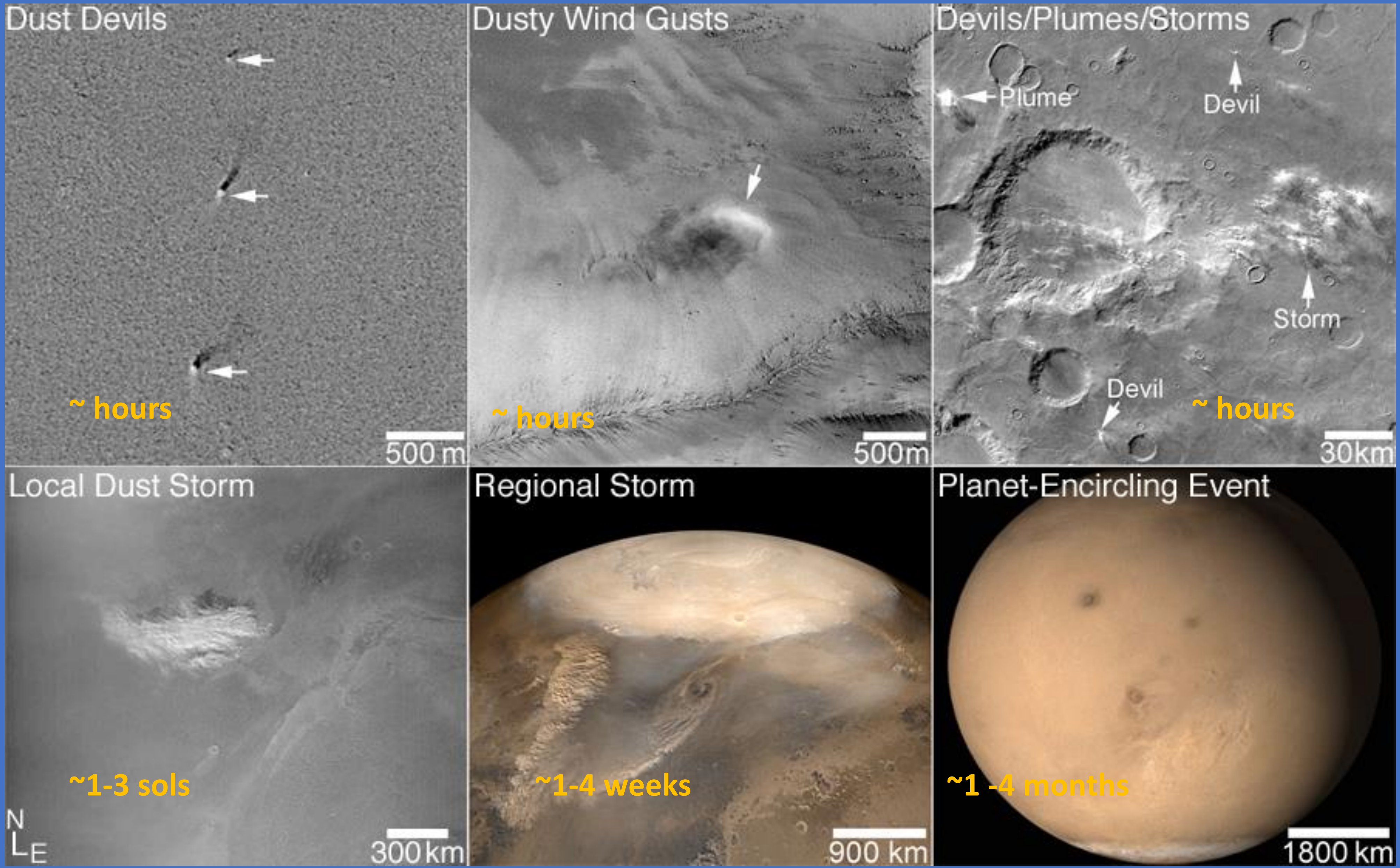
Surface Dust Climatology

- Other representations of climatologies of observed atmospheric dust:
  - **http://www-mars.lmd.jussieu.fr/mars/dust_climatology/**
- From surface thermal inertia, the following surface dust index map has been constructed:





2.0
1.5
1.0
0.5
0.0
Opacity
0
30
60
90
120
150
180
210
240
270
300
330
360
Solar longitude

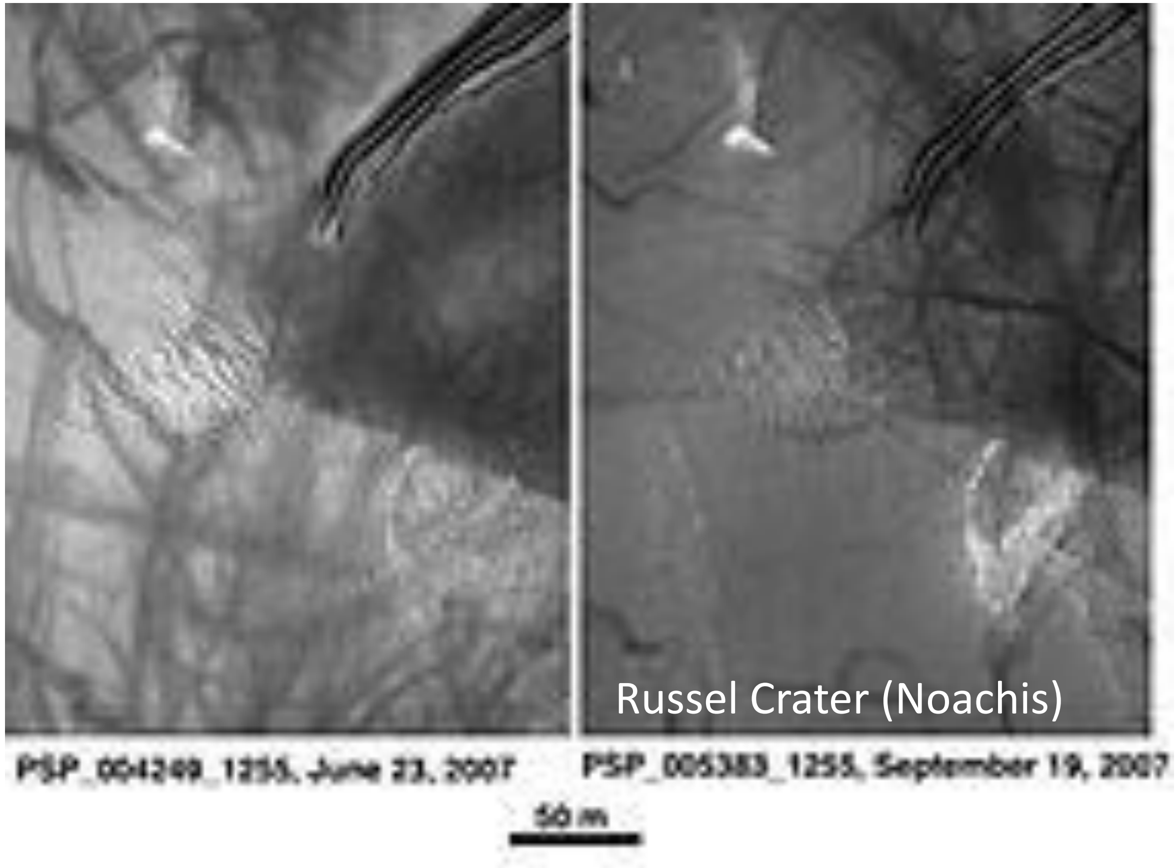


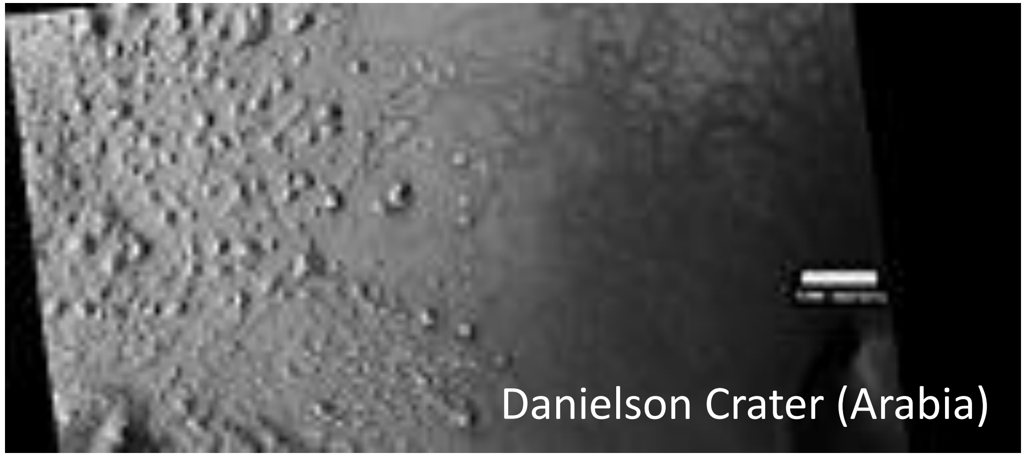
Courtesy of B. Cantor   MSSS / JPL / NASA

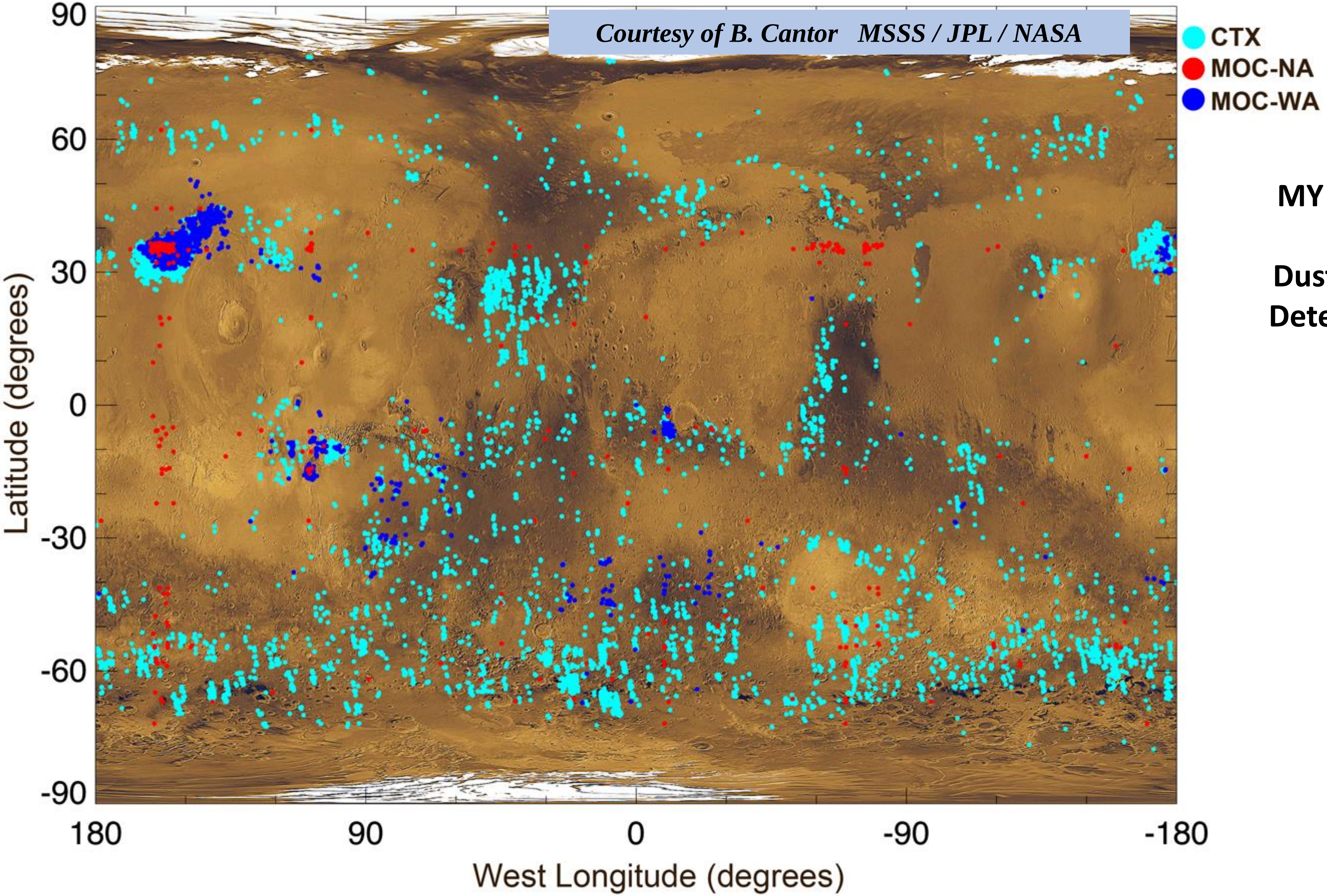
Dust Devils

- ➢Form by the daily heating of surfaces
- ➢Can reach throughout the planetary boundary layer (several kilometers)
- ➢Responsible for surface darkening even of very large areas

MRO HiRISE
LPL / U. Arizona / JPL / NASA

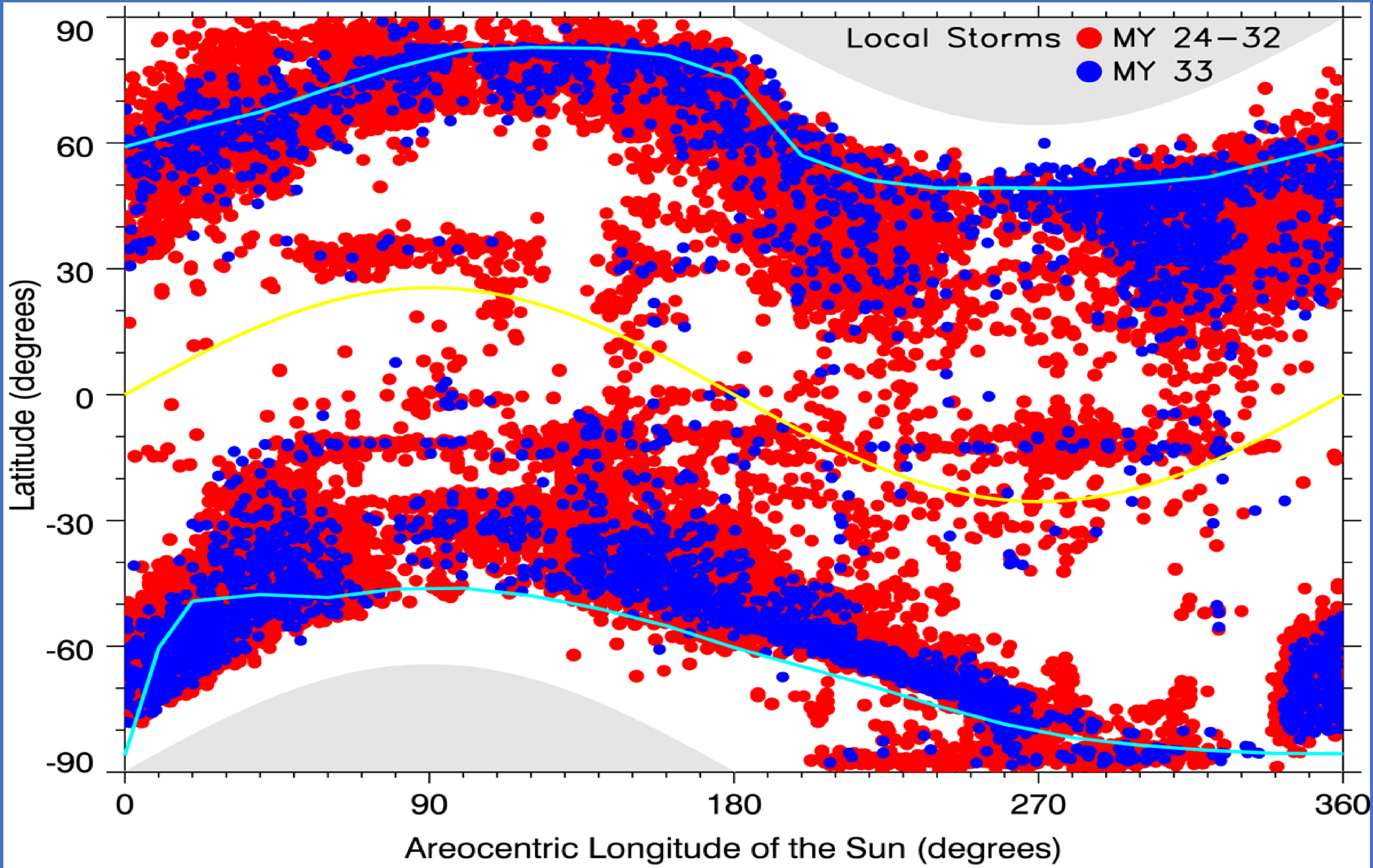






MY 24-32

Dust Devil Detections



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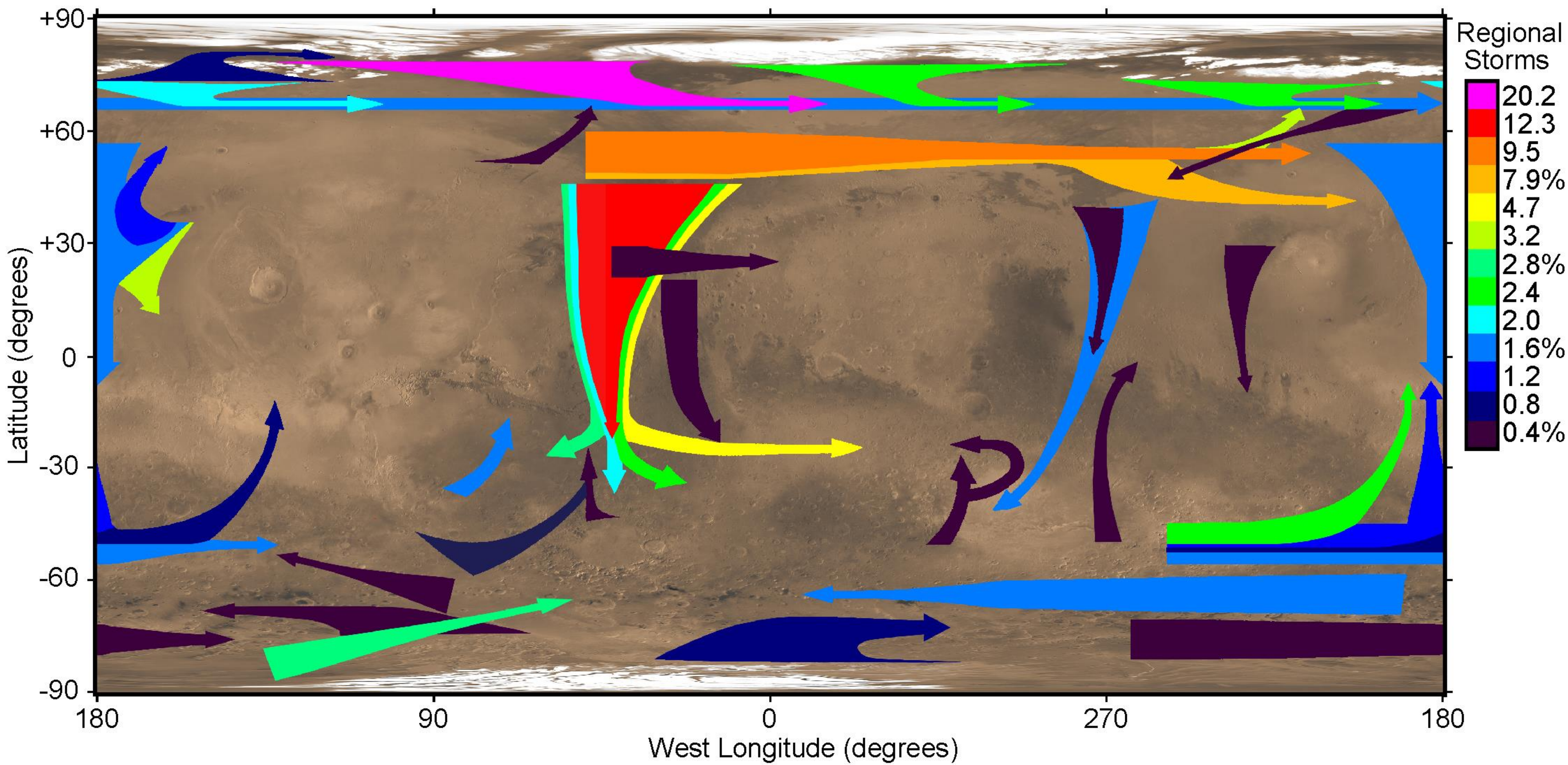

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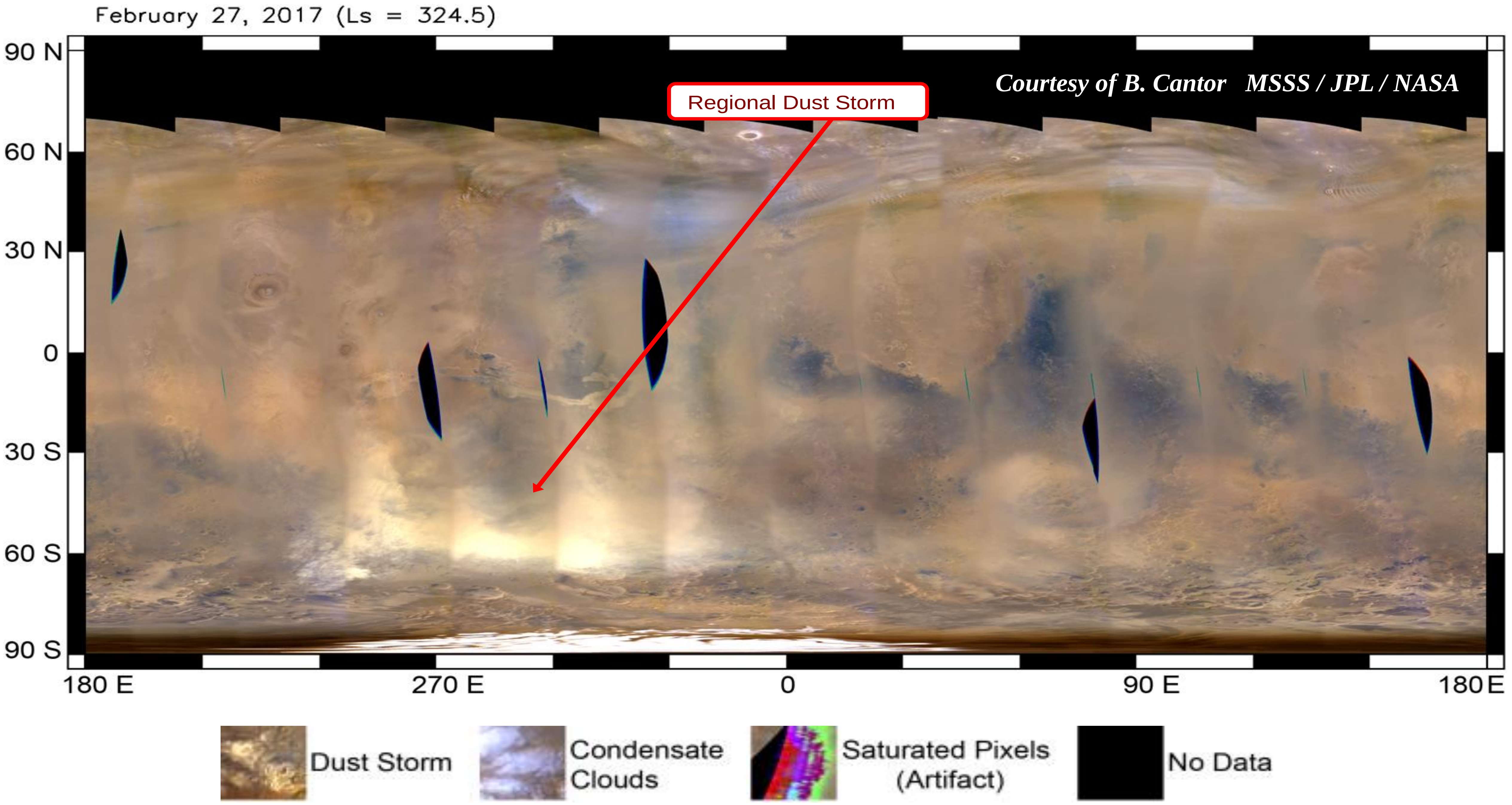
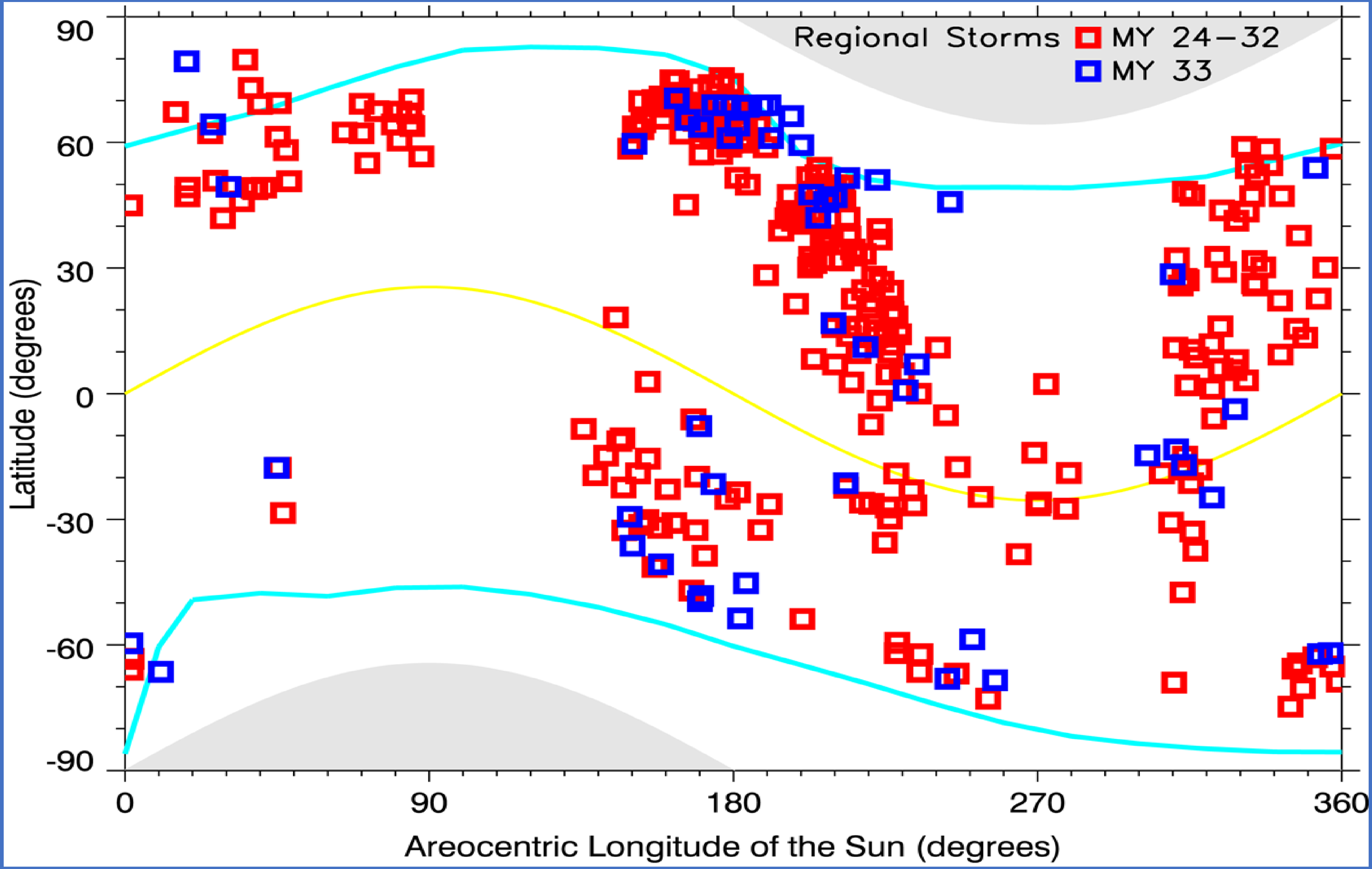
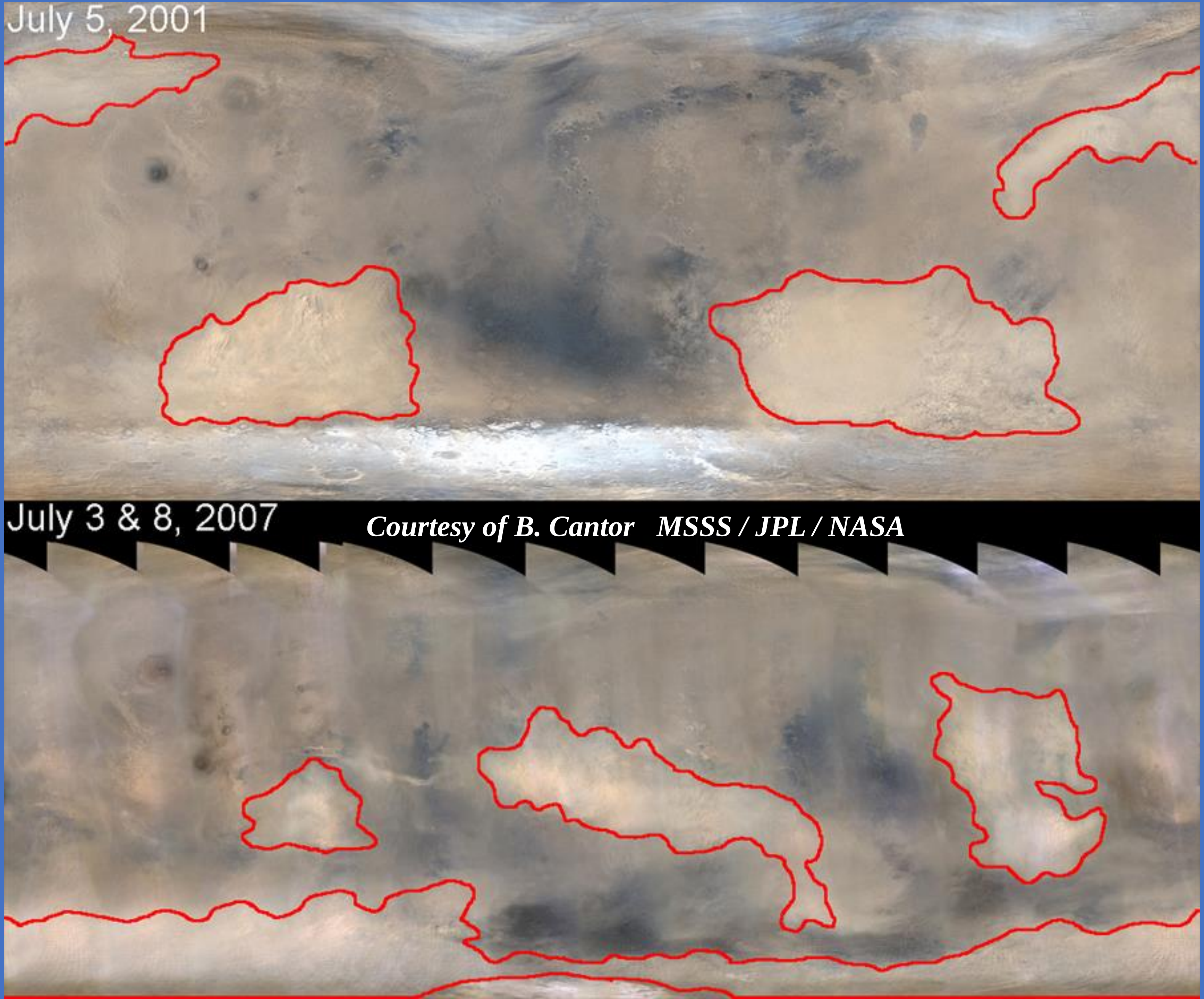
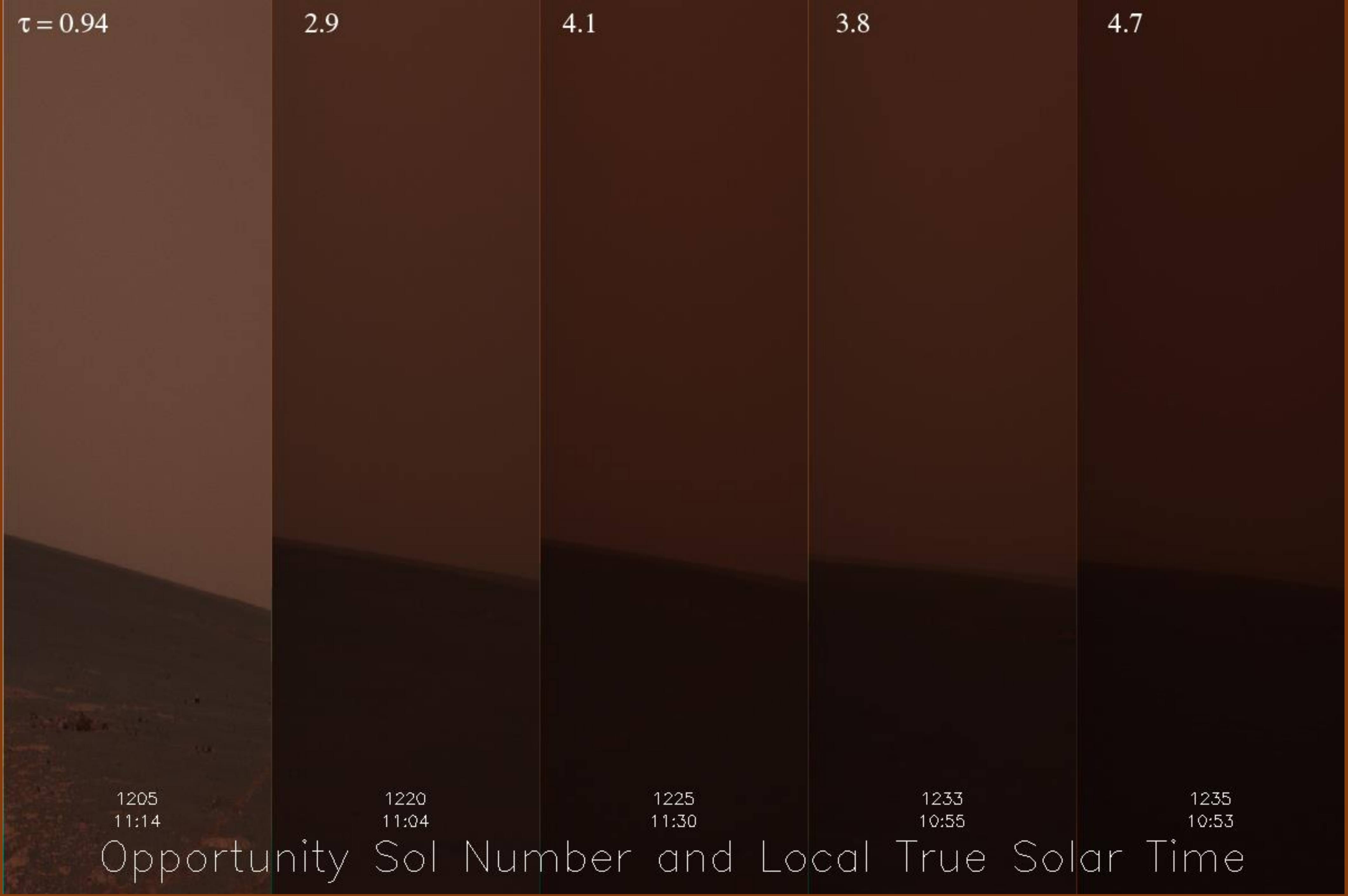


February 27, 2017 (Ls = 324.5)
Courtesy of B. Cantor MSSS / JPL / NASA
Regional Dust Storm
90 N
60 N
30 N
0
30 S
60 S
90 S
180 E
270 E
0
90 E
180 E
Dust Storm
Condensate Clouds
Saturated Pixels (Artifact)
No Data

Courtesy of B. Cantor MSSS / JPL / NASA




July 5, 2001
July 3 & 8, 2007
Courtesy of B. Cantor MSSS / JPL / NASA

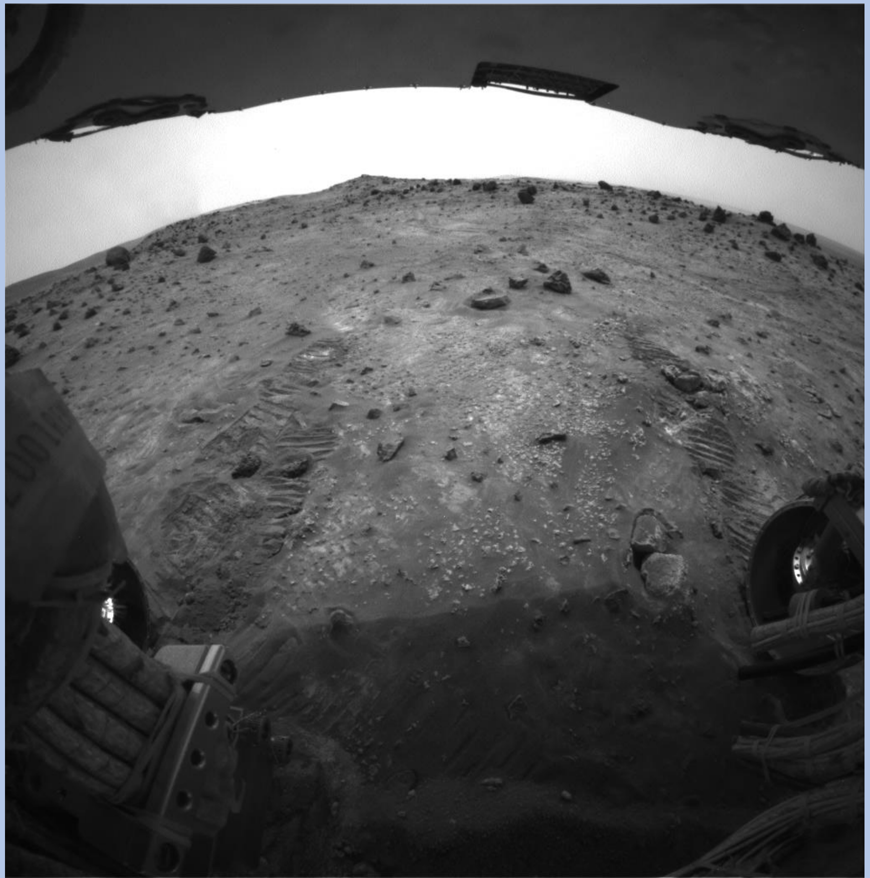


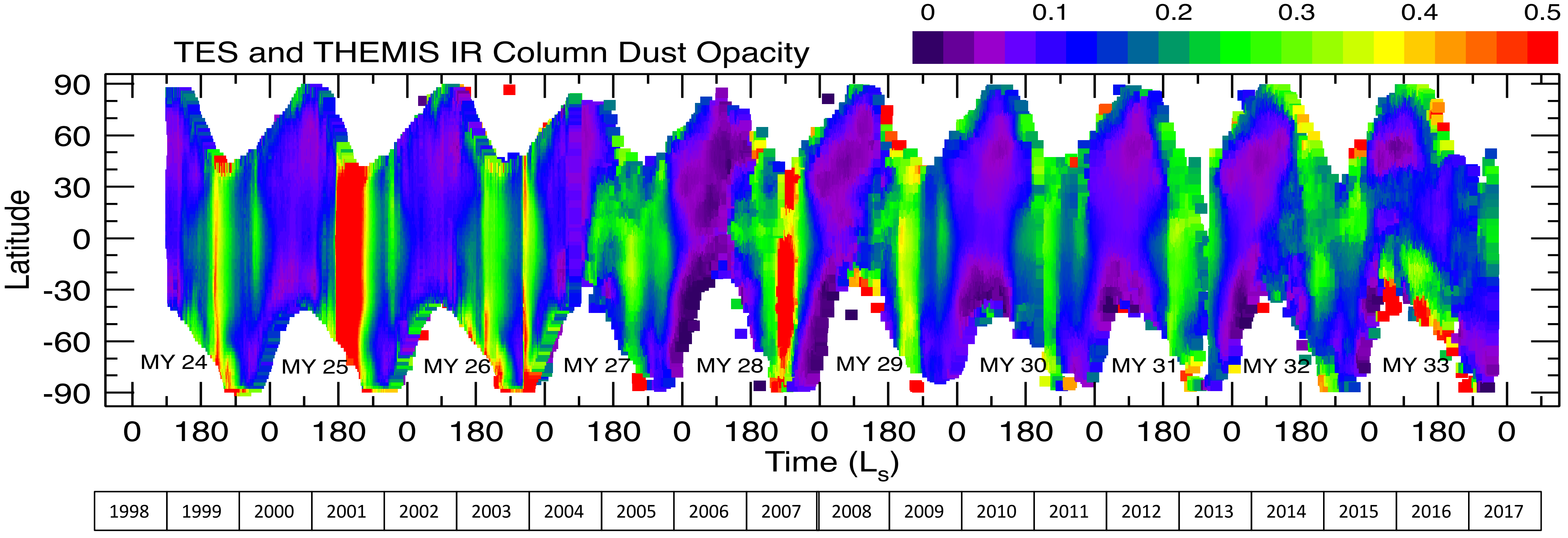
Lemmon, MER-Opportunity Science Team

Spirit Saw Surface Changes

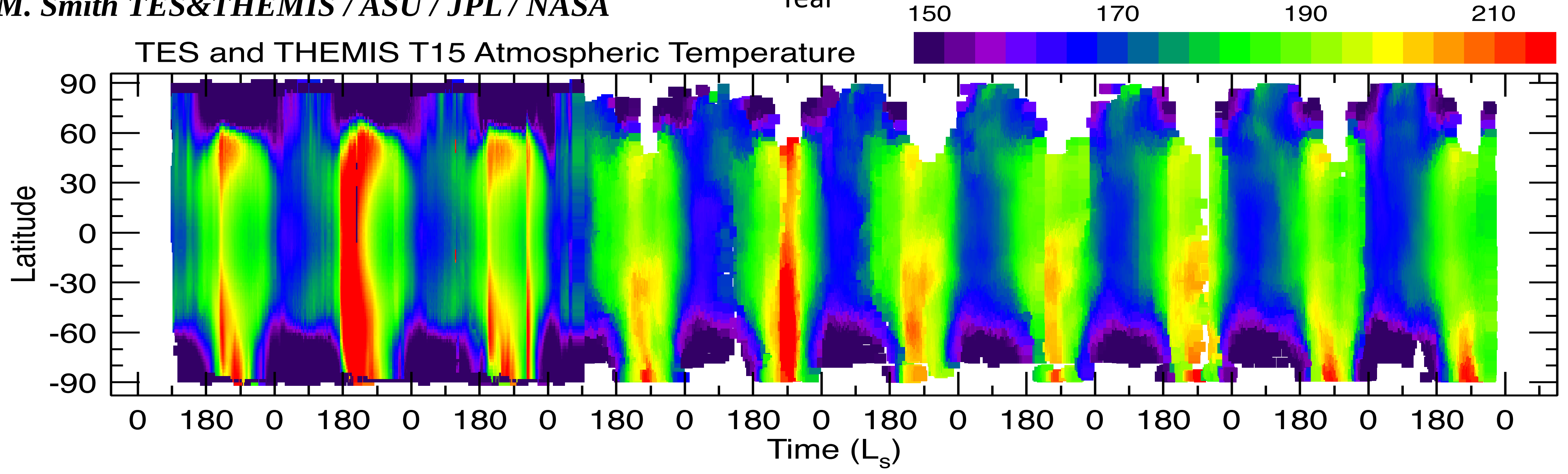
The first image of this animation shows a rear hazcam image of the tracks left in the soil by Spirit as it approached its present position. In the second image, acquired 22 sols later, the tracks have been almost obliterated.

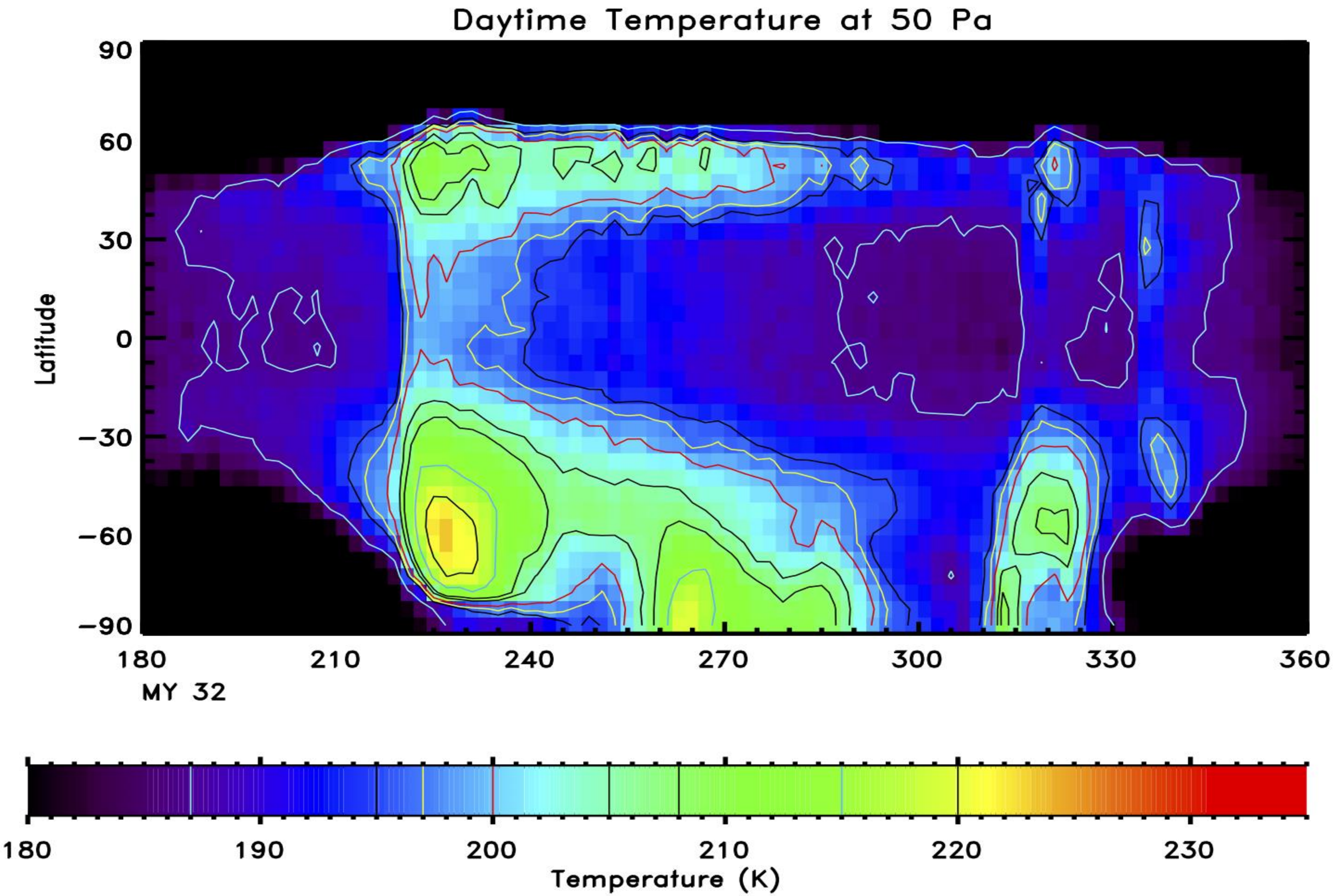
Spirit captured this pair of front hazcam images (taken five sols apart) showing the motion of ripples being blown by the wind. This is the first time this motion has been "caught in the act" on Mars.



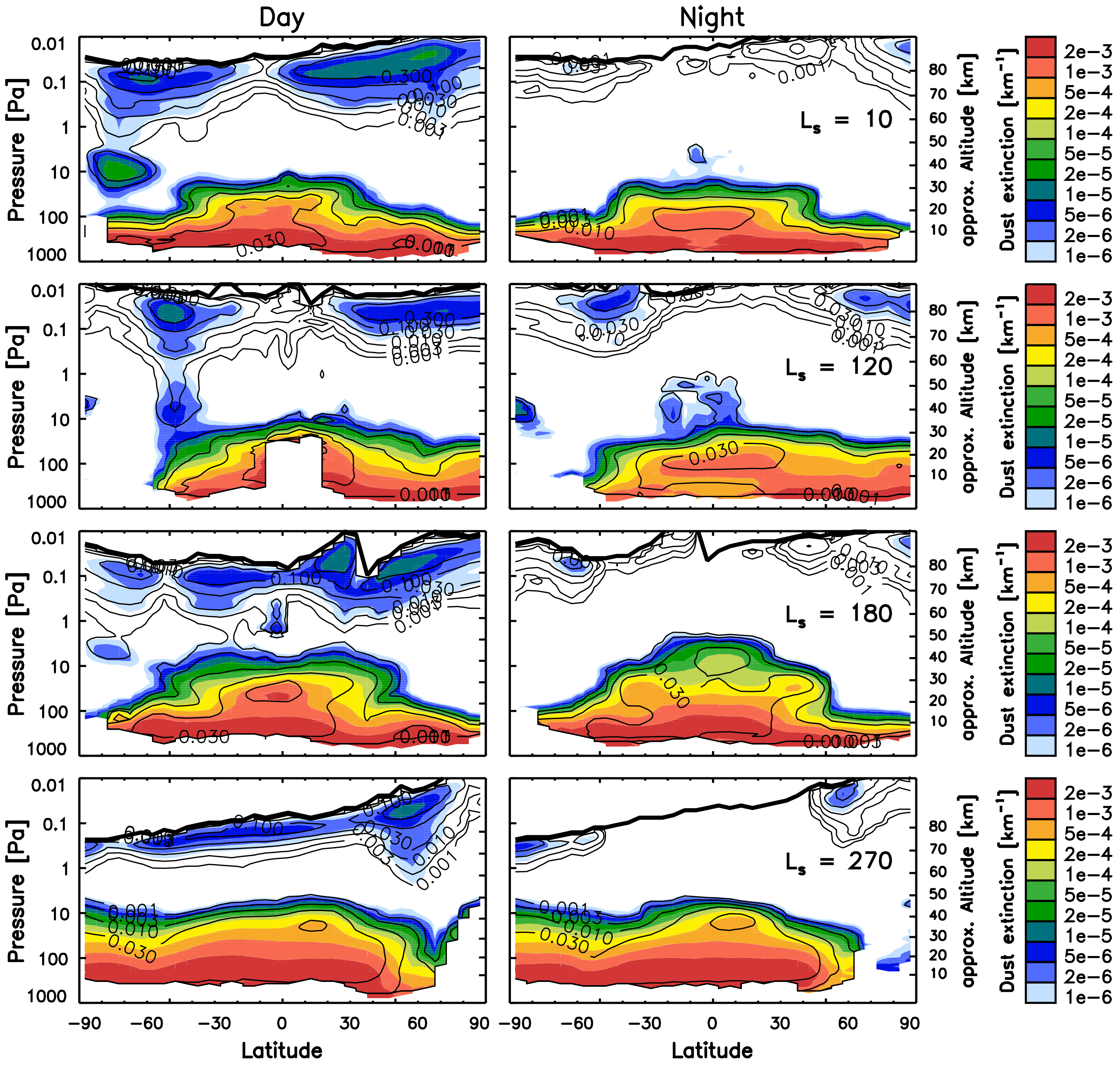


Courtesy of M. Smith TES&THEMIS / ASU / JPL / NASA



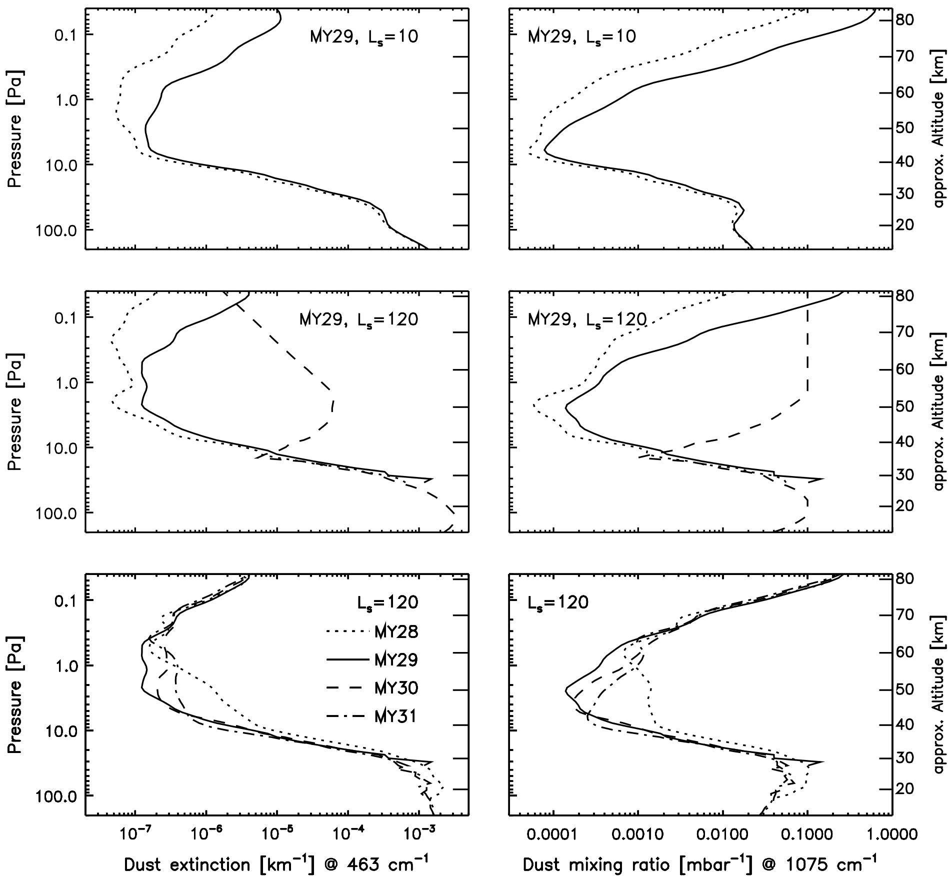


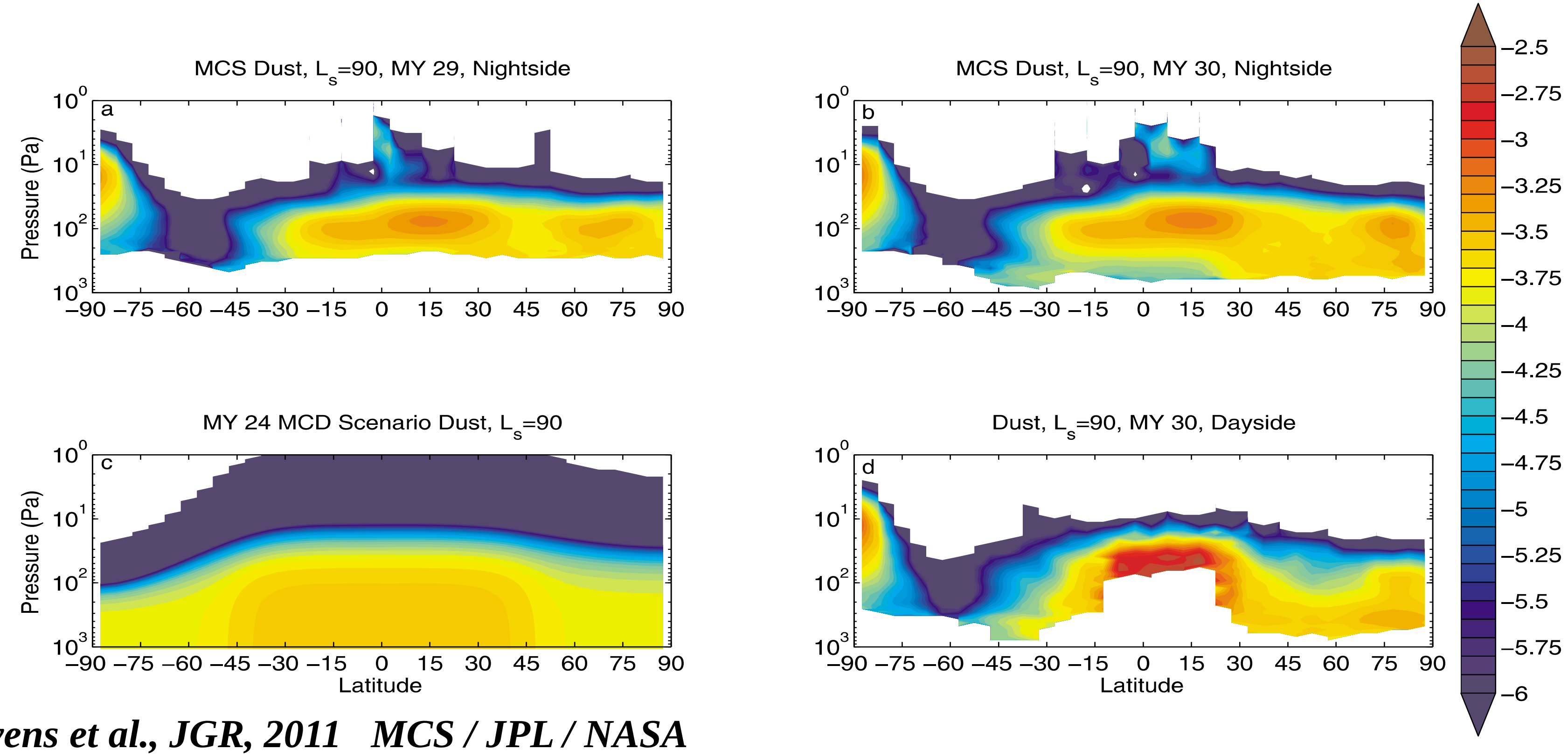
Kass et al., Geophys. Res. Ltr., 2016
MCS / JPL-Caltech / NASA



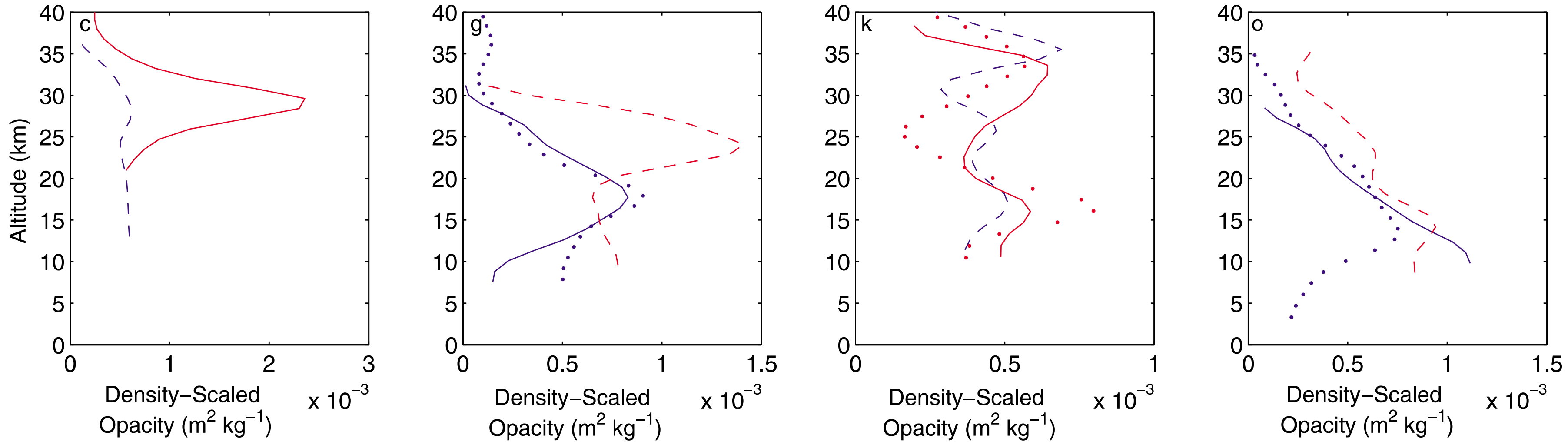
Kleinbohl et al., 2015
***Icarus* 261, pp. 118-121**

Based on MRO MCS Retrievals





Heavens et al., JGR, 2011   MCS / JPL / NASA



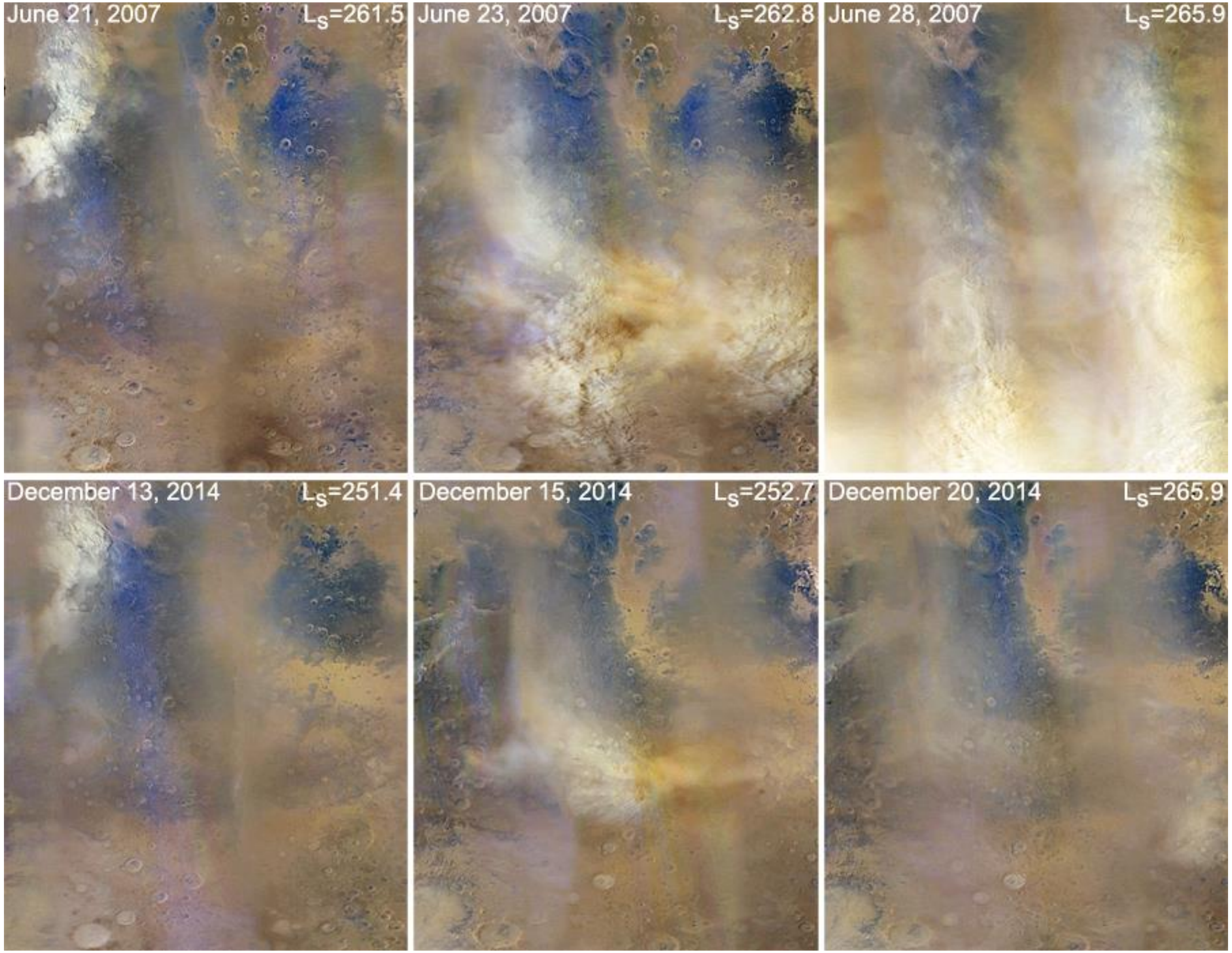
Interannual Variability – Chaotic Element?

Mars Year 28 (June 2007)

Local storm moves down the Acidalia storm track, crosses the equator and blooms into a regional and then planet-encircling dust storm in late southern spring.

Mars Year 32 (December 2014)

Local storm moves down the same Acidalia track, crosses the equator at nearly the same season, but remains a local dust event.



Courtesy of B. Cantor   MSSS / JPL / NASA

Summary

- **There is *some* dust in the Mars atmosphere *everywhere* on the planet essentially *all the time* (the background dust haze)**
  - There may be clear atmospheric air in some air masses where dust has been scavenged but typically not for long outside the polar regions
  - There are some places on the surface where dust (the fine-grained particles < 50 µm in diameter) has been removed by the winds
  - Every dust storm is different in detail
- **The amount of atmospheric dust varies dramatically with season. Local dust storms and dust devils occur in all seasons and have been observed almost everywhere on the planet at some time. However, there are:**
  - Preferred zones of occurrence, some varying with season
  - There are storm tracks where local dust storms repeatedly travel
  - The largest dust storms, covering regional (Earth continent-size) and even global domains, tend to occur during southern spring and summer, when Mars is closest to the Sun and the feedback of heating of the airborne dust is strongest.
    - Heating => temperatures => pressure => winds => dust-raising => more heating
    - But regional storms can occur in other seasons as well